Amendment to the Specification

In the Specification:

Please amend the specification as follows:

On page 1, line 3 after the title, please add the following section heading and paragraph:

Related Applications

This application is a continuation-in-part (CIP) of a patent application, Serial No. 09/496,999, filed on February 3, 2000, which was co-pending at the time this application was filed and is now issued as U.S. Patent No. 6,537,506, the benefit of the filing date of which is hereby claimed under 35 U.S.C. § 120.

On Page 25, before the paragraph and heading beginning at line 29, please add the following new paragraphs (this addition represents disclosure being imported from the parent application in which priority is claimed, as noted above, and does not represent new matter).

Another aspect of the present invention is a microreactor for use in the modular reaction system, for reacting one chemical with at least one other chemical, for the purpose of forming a chemical product. The reactor includes a plurality of simple plates, each simple plate having at least one opening formed therein, the simple plates being stacked together to form a plurality of layers and arranges so that at least one opening in each simple plate overlaps at least one other opening in an adjacent simple plate, thereby forming at least one pathway between at least some of the layers.

Preferably, openings within different layers align so as to form at least one inlet port and at least one outlet port, for the receipt and discharge of chemicals, and to form at least one pathway for conveying chemicals to be processed. At least one pathway is formed that is in fluid connection with the inlet and outlet ports, and each simple plate has at least one opening formed in it.

LAW OFFICES OF RONALD M. ANDERSON
600 - 108th Avenue N.E., Suite 507
Bellevue, Washington 98004
Telephone: (425) 688-8816 Fax: (425) 646-6314

A material from which the simple plates are fabricated is selected for compatibility with the chemical process. In one embodiment, the simple plates are formed from a material selected from the group consisting of crystalline wafers, ceramics, glasses, polymers, composite materials, and metals. Preferably, if formed from a metal, stainless steel is used. The material of the crystalline wafer is selected from the group consisting of silicon and germanium.

It is also preferable that the reactor accommodate a plurality of operations, including temperature control, control of chemical residence time, chemical mixing, and chemical reacting. Temperature control is achieved using a combination of one or more temperature sensors and one or more heat exchangers. Preferably, chemical mixing is carried out by employing pathways sized so that a reactant achieves a stacked laminar flow with respect to at least one other reactant.

In a reactor adapted for processing at least two reactants to form a desired chemical product, an inlet opening for each of the reactants and an outlet opening for the chemical product is provided in at least one of two outer simple plates. An intermediate simple plate is included for mixing the reactants and has at least one opening in fluid communication with each inlet opening and the outlet opening.

Generally, at least one heat transfer fluid inlet port is included in at least one of the outer simple plates, so that at least one heat transfer fluid can be introduced into the chemical reactor. Each heat exchanger is defined by an opening in a different intermediate simple plate. The opening is in fluid communication with the heat transfer fluid inlet and outlet ports and is disposed between adjacent simple plates.

Preferably, each heat exchanger is used to modify the temperature of at least one of the reactants and/or the chemical product. The heat exchangers can be used to modify a temperature of one of two reactants such that they are at different temperatures.

The thickness of the outer simple plates is about 3 millimeters, and that of the plurality of intermediate simple plates is at least about 0.2 millimeters, but not more than about 0.6 millimeters.

Preferably, when the thickness of the intermediate simple plates that are adjacent to a heat exchanger is about 0.3 millimeters. When a series of openings in the simple plates of the chemical reactor defines a fluid path for a heat transfer fluid that flow through more than one heat exchanger, the flow rate and fluid pressure of the heat transfer fluid within each such heat exchanger are substantially.

LAW OFFICES OF RONALD M. ANDERSON
600 - 108th Avenue N.E., Suite 507
Bellevue, Washington 98004
Telephone: (425) 688-8816 Fax: (425) 646-6314

On Page 8, please amend the paragraph beginning on line 30 as follows:

FIGURE 15 is a simplified process flow diagram for a preferred embodiment of a modular microreactor system that utilizes a serial heat transfer media fluidic system in accord with the present invention[[.]]; and

On Page 8, immediately after the paragraph beginning on line 30 and ending on line 33 (amended as noted above), please add the following new paragraphs (note that this addition represents disclosure being imported from the parent application, and does not represent new matter).

FIGURE 16 is an exploded isometric view of an exemplary reactor, illustrating how sixteen simple plates are stacked to achieve the exemplary reactor;

FIGURE 17A is an exploded isometric view of the first six simple plates of the exemplary reactor, illustrating a fluid path for a first reactant;

FIGURE 17B is an exploded isometric view of the first six simple plates of the exemplary reactor, illustrating a fluid path of a second reactant;

FIGURE 17C is an exploded isometric view of simple plates seven through sixteen of the exemplary reactor, illustrating the combined fluid paths of the first and second reactants after they have been mixed, and then through the balance of the exemplary reactor;

FIGURE 18A is an exploded isometric view of the first two simple plates of the exemplary reactor, illustrating a fluid path for heat transfer media servicing the first heat exchanger;

FIGURE 18B is an exploded isometric view of the first four simple plates of the exemplary reactor, illustrating a fluid path for heat transfer media servicing the second heat exchanger; and

LAW OFFICES OF RONALD M. ANDERSON
600 - 108th Avenue N.E., Suite 507
Bellevue, Washington 98004
Telephone: (425) 688-8816 Fax: (425) 646-6314

FIGURE 18C is an exploded isometric view of the first thirteen simple plates of the exemplary reactor, illustrating the fluid paths for heat transfer media servicing heat exchangers three and four.

On Page 25, before the paragraph beginning at line 5, please add the following new section heading and paragraphs (this addition represents disclosure being imported from the parent application, and does not represent new matter). .

An Exemplary Stacked Plate Microreactor

As noted above, particularly preferred embodiments of the present invention will implement a stacked plate microreactor. The following disclosure, originally provided in the commonly assigned co-pending parent application (U.S. Patent Application, U.S. Serial No. 09/496,999, entitled "MINIATURIZED REACTION APPARATUS," which was filed February 3, 2000), describes a reactor for reacting one chemical with at least one other chemical, for the purpose of forming a chemical product. The reactor includes a plurality of simple plates, each simple plate having at least one opening formed therein, the simple plates being stacked together to form a plurality of layers and arranges so that at least one opening in each simple plate overlaps at least one other opening in an adjacent simple plate, thereby forming at least one pathway between at least some of the layers.

Unlike prior art stacked layer chemical reactors that require relatively complicated surface features, such as grooves or channels that do not penetrate the component to be formed into each layer, the simple plates employed in the present invention require no more than an opening be formed through each plate. Machining or stamping openings into a flat plate is significantly less complicated than the silicon etching, injection molding, and ceramic molding/sintering processes described in the prior art for producing the surface features that the prior art uses to channel fluid flow. Yet the relatively simple technique of forming openings in a flat plate can be used to achieve a very useful chemical reactor, if the openings are properly placed, and the plates are properly configured and stacked so that the openings in the plates cooperate to convey fluids through the apparatus.

In the following description and the claims that follow, it will be understood that the term "simple plate" means a plate that has substantially planar opposed surfaces, e.g., a flat sheet of

LAW OFFICES OF RONALD M. ANDERSON
600 - 108th Avenue N.E., Suite 507
Bellevue, Washington 98004
Telephone: (425) 688-8816 Fax: (425) 646-6314

material. In an exemplary reactor, no openings penetrate the peripheral edges defining the perimeter of the simple plates ,and fluid passages used to implement heat exchangers are not in fluid communication with fluid passages for reactants or products, or fluid passages corresponding to reaction volumes and mixing volumes. The simple plates used in the embodiments of the present invention disclosed herein are all generally rectangular and are characterized by having one or more openings that pass completely through the simple plate. Thus, the term "simple plate" as used herein and in the claims should be understood to mean a plate that does not include any etchings, grooves, or channels that do not completely penetrate the plate.

The term "groove," as used herein, should be understood to mean a surface feature that has been formed into the surface of an object that does not penetrate completely through the object, and applies to components of prior art chemical reactors.

The plurality of stacked simple plates enables a reactor to be constructed that performs from one to all of the following functions: reactant conditioning, control of reactant supply, thermal pre-treatment, combination and mixing of reactants under controlled thermal conditions, intermediate thermal treatment, post-procedural isothermal containment, post-procedural thermal treatment of reactant products, and product separation. In particular, simple plates can readily be designed and fabricated in which the dimensional characteristics of the reactant fluid passages formed by the interconnected openings of the simple plates provide for a stacked laminar flow of the reactants. Such a stacked laminar flow ensures that a particularly efficient type of mixing, referred to as diffusion mixing, can occur.

The fluidic system of the stacked simple plate reactor is preferably characterized by having a small pressure drop across the entire system. Furthermore, potential clogging problems are minimized by having few constrictions within the reactor, by introducing as few sharp directional flow changes as possible, by maintaining a small inner volume (about 1 ml), and by enabling rapid diffusion mixing in the mixing portion of the reactor. Preferably, fluidic channel geometries range from 100-500 μm, especially with respect to reactant fluid pathways (the dimensions of any heat transfer media pathways are less critical), and the walls separating the heat transfer media from the reactants or product should be of similar scale, to enable rapid heat transfer. As discussed above, several materials can be used to fabricate a stacked simple plate reactor; however, simple plates that are adjacent to openings in those simple plates comprising heat exchangers are preferably fabricated

LAW OFFICES OF RONALD M. ANDERSON
600 - 108th Avenue N.E., Suite 507
Bellevue, Washington 98004
Telephone: (425) 688-8816 Fax: (425) 646-6314

from a material that has good thermal conductivity. However, if the dimensional thickness of each plate adjacent to a heat exchanger is small, on the order of 0.3 mm, the effect of the thermal conductivity of different materials is negligible.

In general, the openings in each simple plate of a stacked simple plate reactor correspond to a fluid pathway established by stacking a plurality of simple plates, such that openings in simple plates above and below overlap, thereby allowing fluids to move throughout the reactor. Openings may also correspond to passageways for sensors, particularly temperature sensors. Preferably, to maximize heat transfer, the fluid flow directions of the heat transfer media within openings defining a heat exchanger are opposite to the direction of reactant flow.

FIGURE 17 is an exploded isometric view of a preferred reactor 100 that includes the sixteen layers. Simple plates 110-260 are shown stacked in order so that the relative positions of each simple plate to each other may be examined. The preferred dimensional thickness of each simple plate is as follows:

Top simple plate 110:	3.0 mm.
Second simple plate 120:	0.3 mm.
Third simple plate 130:	0.3 mm.
Fourth simple plate 140:	0.3 mm.
Fifth simple plate 150:	0.3 mm.
Sixth simple plate 160:	0.3 mm
Seventh simple plate 170:	0.2 mm.
Eighth simple plate 180:	0.3 mm.
Ninth simple plate 190:	0.6 mm
Tenth simple plate 200:	0.3 mm.
Eleventh simple plate 210:	0.2 mm.
Twelfth simple plate 220:	0.3 mm
Thirteenth simple plate 230:	0.6 mm.
Fourteenth simple plate 240:	0.3 mm.
Fifteenth simple plate 250:	0.3 mm
Sixteenth simple plate 260:	3.0 mm

Simple plates 110 and 260 (the top and bottom simple plates) are thicker than other plates to provide greater structural stability. Simple plates 120-160, 200, 220, 240 and 250 are much thinner, to enhance heat transfer. As will be discussed below, a thickness of 0.3 mm provides a reasonable heat transfer ability for a wide variety of materials.

For simple plates that include solid portions used to transfer thermal energy to or from heat exchangers, a preferred thickness is about 0.3 mm. As plate thickness increases, mechanical stability increases and heat transfer ability decreases. The 0.3 mm thickness provides good heat transfer

LAW OFFICES OF RONALD M. ANDERSON
600 - 108th Avenue N.E., Suite 507
Bellevue, Washington 98004
Telephone: (425) 688-8816 Fax: (425) 646-6314

characteristics without sacrificing mechanical stability. When graphs representing mechanical stability as a function of plate thickness (50μm-1 mm) and heat transfer ability as a function of plate thickness (50μm-1 mm) are combined, the curves representing each functional relationship intersect at approximately 0.3 mm. It should be noted that this optimum value of 0.3 mm is independent of the actual material selected (glass, metal, plastic, etc.). While the shape of the curves defining the functional relationships change when a different material is selected, the intersection of the curves at 0.3 mm remains relatively constant. Thus, 0.3 mm represents a simple plate thickness that provides for reasonable heat transfer ability without sacrificing structural integrity.

FIGURE 17A illustrates a fluid flow path of Reactant A, as it enters top simple plate 110 and proceeds through the sixth simple plate 160 of reactor 100. Reactant A enters through an inlet 115 in top simple plate 10, proceeds to second simple plate 120 of the second layer, and enters a Reactant A distributor 125. Reactant A then passes to third simple plate 130 of the third layer, passing through four Reactant A openings 135. In fourth simple plate 140 of the fourth layer, Reactant A passes through four Reactant A openings 145, which are part of an inter-digital-mixer, whose purpose is to precisely align the fluid flows for Reactants A and B to optimize mixing in later layers of the reactor. The purpose of Reactant A openings 145 is to precisely align a plurality of Reactant A fluid paths with a plurality of Reactant B fluid paths, so that a stacked laminar flow can be achieved with equilibrated pressure drops. It should be noted that a first heat exchanger 124 (see FIGURE 17A) is used to bring both Reactants A and B to the proper temperature in the inter-digital-mixer of the fourth layer.

In the fifth layer, fifth simple plate 150 incorporates a plurality of reactant A openings 155 that are aligned with a plurality of Reactant B openings 157 (see FIGURE 17B). These openings form an alternating pattern of 24 openings in four rows of six openings each (for a total of 12 Reactant A openings and 12 Reactant B openings). In the sixth layer, sixth simple plate 160 incorporates four fluid channels 165. It is in the four channels 165 that Reactants A and B first intermingle. Because of the pattern of fluid paths for Reactants A and B enabled by the inter-digital-mixer, Reactants A and B enter channels 165 in a stacked laminar flow pattern.

FIGURE 17B illustrates the fluid path that Reactant B takes in entering the first six layers of a reactor 100. Reactant B enters top simple plate 110 through opening 117, passes through the second layer an identical Reactant B openings 117 in second simple plate 120. In the third layer, Reactant B

LAW OFFICES OF RONALD M. ANDERSON
600 - 108th Avenue N.E., Suite 507
Bellevue, Washington 98004
Telephone: (425) 688-8816 Fax: (425) 646-6314

enters Reactant B distributor 137 in third simple plate 130. In the fourth layer, Reactant B enters four Reactant B openings 147 in fourth simple plate 140. Openings 147 and 145 are collectively referred to as the inter-digital-mixer. After passing through the fourth layer, Reactant B flows into twelve openings 157 in fifth simple plate 150, of the fifth layer. Reactant B then proceeds to the four fluid channels 165 on sixth simple plate 160, where Reactants A and B are first co-mingled.

FIGURE 17C illustrates the combined flows of Reactants A and B after passing through the sixth layer and proceeding through layers 7-16 of reactor 100. Reactants A and B as combined (in a stacked laminar flow pattern) flow through four fluid channels 175 on seventh simple plate 170. Channels 175 lead to four mixing chambers 177. In mixing chambers 177, the stacked laminar flow is compressed, further enhancing rapid diffusion mixing. A second heat exchanger 146 (see FIGURE 18B) is used to control the temperature of the reactants as they mix in mixing chambers 177. After Reactants A and B become thoroughly mixed in mixing chambers 177, the now mixed Reactants A and B flow through a plurality of mixed reactant openings 185 on eighth simple plate 180. The mixed reactants then flow through the ninth and tenth layers via identical mixed reactant openings 185 in simple plates 190 and 200, respectively. The mixed reactants then flow into reaction channels 116 on eleventh simple plate 210. Reaction channels 116 preferably provide sufficient residence time so that the majority (if not all) of the reaction is complete. If reaction channels 116 do not provide sufficient residence time, then an additional residence time chamber can be added downstream of reactor 100. As noted above, the quality and yield of the desired reaction is greatly affected by the ability to control temperature during the reaction process. The preferred reactor provides heat exchangers on simple plates 190 and 230 to precisely control the temperature within reaction channels 116. If additional residence time chambers are required, then control of the temperature in the additional residence time chambers is also highly desirable. After passing through reaction channels 116 in the eleventh layer, the resulting product passes through a plurality of product openings 126 in simple plates 220, 230, and 240 of layers 12, 13 and 14, respectively. The eight individual product streams represented by these product openings are then combined into a single product channel 156 on fifteenth simple plate 250, of layer 15. This single product exits the reactor via a product outlet 167 on sixteenth simple plate 260, in the bottom (sixteenth) layer of the reactor.

FIGURES 18A-18C illustrate the fluid paths for heat transfer media A, B, and C throughout the preferred reactor. FIGURE 18A illustrates the fluid path for heat transfer media B, which

LAW OFFICES OF RONALD M. ANDERSON
600 - 108th Avenue N.E., Suite 507
Bellevue, Washington 98004
Telephone: (425) 688-8816 Fax: (425) 646-6314

services first heat exchanger 124 in the second layer. Heat transfer media B flows into heat transfer media inlet 114a in top simple plate 110 and proceeds to heat exchanger 124 on second simple plate 120. Heat transfer media B passes through heat exchanger 124, and exits heat exchanger 124 via outlet port 114b in top simple plate 110. The purpose of heat exchanger 124 is to adjust the temperature of the solid section of portion of the third layer that is immediately above the inter-digital-mixer (openings 145 and 147) in fourth simple plate 140. In this manner, heat exchanger 124 is moderating the temperatures of Reactants A and B prior to the reactants being mixed together. It is contemplated that for the majority of reactions, it will be desirable for Reactants A and B to be of similar temperature. Those of ordinary skill in the art will readily understand, however, that there may be some reactions in which Reactant A and Reactant B will preferably be kept at separate temperatures. It is contemplated that a different stacked plate design using the same principles of the invention can be designed and fabricated to provide for a separate heat exchanger to individually modify the temperatures of Reactants A and B.

FIGURE 18B illustrates the fluid path that heat transfer media C takes through layers 1-4 of the preferred reactor. Heat transfer media C enters the reactor through inlet 116a in top simple plate 110 and then proceeds through heat transfer media C intake manifolds 126a on simple plates 120 and 130, in layers 2 and 3, respectively. Heat transfer media C then enters heat exchanger 146 on fourth simple plate 140 of layer 4 and exits heat exchanger 146 by utilizing heat transfer media C exhaust manifolds 126b of simple plates 130 and 120, in layers 3 and 2, respectively. Heat transfer media C then exits the reactor using outlet port 116b of top simple plate 110. The purpose of second heat exchanger 146 is to modify the temperature of the solid portion of sixth simple plate 160 that corresponds to the mixing chambers 177 of seventh simple plate 170. Because the mixing of chemicals often spontaneously generates heat, a great deal of heat can be generated as Reactants A and B are thoroughly mixed. Second heat exchanger 146 is thus able to cool Reactants A and B while in mixing chambers 177, so that the temperatures of the reactants do not exceed the ideal temperature for the desired reaction. Second heat exchanger 146 occupies both the fourth and fifth layers (simple plates 140 and 150), to increase the capacity of the heat exchanger.

FIGURE 18C illustrates the fluid path for heat transfer media A as it passes through the first thirteen layers of preferred reactor 100. Heat transfer media A enters the reactor at top simple

LAW OFFICES OF RONALD M. ANDERSON
600 - 108th Avenue N.E., Suite 507
Bellevue, Washington 98004
Telephone: (425) 688-8816 Fax: (425) 646-6314

plate 110 via intake port 112a. The heat transfer media A then passes through identical heat transfer media A intake manifolds 122a on simple plates 120 and 130 of layers 2 and 3 respectively. Heat transfer media A continues to pass through heat transfer media A intake manifolds in layers 4, 5, 6 and 7, via intake manifolds 142a. It should be noted that intake manifolds 142a differ in size and shape relative to the intake manifolds 122a of layers 2 and 3. The functional purpose of the size change is both reduce potential pressure drops within the fluid paths of the reactor, as well as to reduce the surface area of simple plates 140-170 to enhance bonding.

In layer 8, the shape of heat transfer media A intake manifold 182a changes once again. The purpose of the size change between the heat transfer media A intake manifolds in layers 7 and 8 is so that heat transfer media A can be fed into two separate sections of the layer 9. In a first heat transfer media A fluid path in layer 9, heat transfer media A flows into a heat transfer media A intake manifold 142a, and from there to heat transfer media A intake manifold 42a of tenth simple plate 200 in layer 10. From there, heat transfer media A flows to heat transfer media A intake manifold 142a in layer 11, an enlarged heat transfer media A intake manifold in layer 12, and then to heat transfer media A intake manifold 142a in layer 13.

In a second heat transfer media A fluid path in layer 9, fluid flows out of heat transfer media A intake manifold 182a of eighth simple plate 180 and into third heat exchanger 193 on ninth simple plate 190 of layer 9. The purpose of third heat exchanger 193 is to moderate the temperature of the solid portion of layer 10 immediately adjacent to reaction channels 116 in layer 11. Heat transfer media A exits heat exchanger 193 by returning to layer 8 via heat transfer media A exhaust manifold 182a, which is enlarged and overlaps the right end of third heat exchanger 193.

Simple plate 200 of layer 10 includes enlarged heat transfer media A intake manifold 182a (as well as exhaust manifold 182b). It should be noted that reaction channels 116 of layer 11 are not quite long enough to overlap the enlarged heat transfer medial intake and exhaust manifolds 182a and 182b, thus no heat transfer media enters reaction channels 116. Here, the functional purpose of the size change of the intake and exhaust manifolds is to reduce the surface area of tenth simple plate 200, to enhance bonding, rather than to feed a heat exchanger (as in layer 8 and eighth simple plate 180).

Referring now to layer 11, note that again the size and shape of heat transfer media A intake manifold 142a has changed relative to the intake manifolds of layers 8 and 10. This size change

LAW OFFICES OF RONALD M. ANDERSON
600 - 108th Avenue N.E., Suite 507
Bellevue, Washington 98004
Telephone: (425) 688-8816 Fax: (425) 646-6314

relates to maintaining a calculated fluidic equilibrium throughout the micro reactor. However, it is contemplated that the overall effect of the size change is relatively minor, and that an effective micro reactor can be achieved without changing the size of the intake manifolds on layer 11.

In layer 12, the size and shape of heat transfer media A intake manifold 182a is again enlarged, to once again divert some heat transfer fluid A into a second fluid path that services fourth heat exchangers 133a and 133b of layer 13. Heat transfer media A also flows into a heat transfer media A intake manifold 42a in layer 13. The functional purpose of heat transfer media A intake manifold 142a of layer 13 is to ensure that the fluid pressure within fourth heat exchangers 133a and 133b matches the fluid pressure within third heat exchanger 193. Note both the third and fourth heat exchangers are moderating the temperature of reaction channels 116, and thus preferably both heat exchanges should have similar flow characteristics.

Heat transfer fluid A that has entered fourth heat exchangers 133a and 133b exits layer 13 via heat transfer media A exhaust manifold 142b in layer 12. From there, heat transfer media A moves successively through heat transfer media exhaust manifolds 142b in layer 11, 182b in layer 10, 142b in layer 9, 182b in layer 8, 142b in layers 7-4 and 122b in layers 3-2. Heat transfer media A finally exits the reactor via outlet 112b in top simple plate 110.

Generally the heat transfer media used in the preferred reactor will be liquids, although it is envisioned that selected gases may also be beneficially employed. Fluidized solid heat transfer media (such as sand or silica) are known in the art, and might be used, though the dimensions involved in the fluid channels of the preferred reactor raise the concern that the solid heat transfer media could cause clogging of the heat transfer pathways.

LAW OFFICES OF RONALD M. ANDERSON
600 - 108th Avenue N.E., Suite 507
Bellevue, Washington 98004
Telephone: (425) 688-8816 Fax: (425) 646-6314